

## Model Prediction for the Transverse Single Target-Spin Asymmetry in inclusive DIS

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**Summary.** — The single-spin asymmetry of unpolarized leptons scattering deep-inelastically off transversely polarized nucleons is discussed. This observable is generated by a two-photon exchange between lepton and nucleon. In a partonic description of the asymmetry the non-perturbative part is given in terms of multiparton correlations: quark-gluon correlation functions and quark-photon correlation functions. Recently, a model for quark-gluon correlation functions was presented where these objects were expressed through non-valence light cone wave functions. Using this model, estimates for the single-spin asymmetries for a proton and a neutron are presented.

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### 1. – Introduction

One of the most fundamental and basic processes in hadronic physics is the deep-inelastic scattering (DIS) of leptons off nucleons,  $l(l) + N(P) \rightarrow l(l') + X$ . Single-spin observables in inclusive DIS with either the lepton or nucleon being transversely polarized strictly vanish due to time-reversal invariance for a single photon exchange [1]. This argument fails if two (or more) photons are exchanged between lepton and nucleon.

Experimentally, a recent measurement of the single-spin asymmetry (SSA) for a transversely polarized nucleon, denoted by  $A_{UT}$ , was performed by the HERMES collaboration [2], and again a result consistent with zero was found within an error of about  $10^{-3}$ . Interestingly, preliminary data taken from (ongoing) precision measurements of  $A_{UT}$  at Jefferson Lab seem to indicate a non-zero effect [3].

A theoretical description of the SSA  $A_{UT}$  in a partonic picture needs to deal with two distinctive and complementary physical situations: The exchange of two photons between the lepton and either (i) one *single* quark or (ii) two *different* quarks. The asymmetry has been studied in Refs. [4, 5, 6, 7] for massless quarks. It was found that this observable generically behaves like  $M/Q$  where  $M$  denotes the nucleon mass,  $Q^2 = -q^2$ , and  $q = l - l'$  the 4-momentum transfer to the nucleon. Thus the asymmetry is a power suppressed ('twist-3') observable, and can be expressed in terms of multipartonic non-perturbative

quark-gluon (scenario (i)) and quark-photon (scenario (ii)) correlation functions. Effects of a finite quark mass proportional to the transversity distribution  $h_1^q(x)$  are also relevant for scenario (i) and have been studied in Ref. [8].

## 2. – $A_{UT}$ in a partonic picture

The DIS differential cross section can be analyzed in terms of the commonly used DIS variables that are defined as  $x_B = Q^2/(2P \cdot q)$  and  $y = P \cdot q/P \cdot l$ . For the description of  $A_{UT}$  a transverse (to the lepton plane) spin vector  $S_T$  of a polarized nucleon is needed. An azimuthal angle  $\phi_s$  between  $S_T$  and the lepton plane determines the spatial orientation of  $S_T$ .

An analysis of the SSA  $A_{UT}$  in inclusive DIS in a partonic picture has to be performed at subleading twist accuracy [4, 6, 7]. This requires the introduction of typical hadronic matrix elements of certain partonic operators that encode non-trivial correlations of the transverse nucleon spin and the transverse partonic motion [9], as well as multipartonic correlations [10, 7]. However, the effects of transverse partonic motion and multipartonic correlations are not independent. In fact, they can be related to each other by means of the QCD-equation of motion (EOM) [9]. An additional dependence originates from the relation between the Sivers function and the so-called Qiu-Sterman matrix element [12]. If one applies the twist-3 factorization formalism of Ref. [11] to the SSA  $A_{UT}$  all of these hadronic matrix elements are to be convoluted with corresponding partonic hard cross sections, and eventually summed up (cf. [6]).

The hard cross sections relevant for scenario (i) are calculated in perturbation theory to  $\mathcal{O}(\alpha^3)$  to obtain a non-zero result. This includes interferences of real lepton-quark(& gluon) scattering amplitudes describing the radiation of a photon emitted by either the lepton or the quark. Such real contributions typically contain phase space integrations. Interferences from virtual two-photon-exchange one-loop diagrams and single photon exchange diagrams may also contribute. The various hard cross sections can be combined by application of QCD-EOM inspired relations between effects of transverse partonic motion and multipartonic correlations, and eventually the soft divergences indicated by poles in  $1/\varepsilon$  cancel [6].

The hard cross sections can be computed along the same lines for scenario (2). To leading order only tree-level diagrams interfere without phase space integrations [7]. Hence, no soft divergences appear in intermediate steps of the calculation.

Adding the results of Refs. [6, 8, 7] leads to the following parton picture formula for the single transverse spin dependent DIS cross section at  $\mathcal{O}(\alpha_{\text{em}}^3)$ ,

$$(1) \quad E' \frac{d\sigma_{UT}}{d^3l'} = -|S_T| \sin \phi_s \frac{4\alpha_{\text{em}}^3}{yQ^4} \frac{M}{Q} \frac{x_B y}{\sqrt{1-y}} \times \\ \sum_q \left[ e_q^3 \int_0^1 dx \left( \hat{C}_+(x, x_B, y) G_F^q(x_B, x) + \hat{C}_-(x, x_B, y) \tilde{G}_F^q(x_B, x) \right) \right. \\ \left. + e_q^3 (1-y) \frac{m_q}{M} h_1^q(x_B) + \frac{2-y}{2y} e_q^2 \left( 1 - x_B \frac{d}{dx_B} \right) G_F^{\gamma, q}(x_B, x_B) \right].$$

The perturbative coefficient functions  $\hat{C}_\pm$  in Eq. (1) are integrable distributions and their functional form is given in Ref. [6]. Assuming that the non-perturbative quark-

gluon correlation functions  $G_F^q(x, x')$  and  $\tilde{G}_F^q(x, x')$ <sup>(1)</sup> are analytic the  $x$ -integral in (1) is well-defined. In addition the finite quark mass term of Ref. [8, 7] has been added to Eq. (1) as well as the contribution of Ref. [7] describing scenario (ii) where the two photons couple to different quarks. The latter term involves a quark-photon correlation function  $G_F^\gamma$ <sup>(2)</sup>.

The SSA  $A_{UT}$  can be computed from (1) in the following way ( $d\sigma = E'd\sigma/d^3k'$ ),

$$(2) \quad A_{UT} = \frac{d\sigma_{UT}(\phi_s) - d\sigma_{UT}(\phi_s - \pi)}{2d\sigma_{UU}},$$

with the well-known parton model result for the unpolarized cross section [9],

$$(3) \quad d\sigma_{UU} = \frac{4\alpha_{\text{em}}^2}{Q^4 y} f(y) \sum_q e_q^2 x_B f_1^q(x_B),$$

with  $f_1$  the unpolarized collinear parton distribution.

### 3. – Model for the quark-gluon correlations from light cone wave functions

In order to utilize Eq. (1) to estimate the sign and size of the transverse target spin asymmetry  $A_{UT}$  on a proton and neutron one needs information on the full support of the non-perturbative quark-gluon correlation functions  $G_F^q(x, x')$ ,  $\tilde{G}_F^q(x, x')$ <sup>(3)</sup>, as well as the quark-photon correlation function  $G_F^{\gamma,q}(x, x)$  in the soft photon limit  $x' = x$  and the transversity distribution  $h_1^q(x)$ . Currently, only extractions from data exist for the so-called "Soft Gluon Pole matrix element"  $G_F^q(x, x)$  [14] and the transversity distribution. However, a recent model calculation gives predictions for  $G_F^q$  and  $\tilde{G}_F^q$  on the full support  $x \neq x'$  [13]. In this work the twist-3 quark-gluon correlation functions are expressed in terms on non-valence-like light cone wave functions, and analytical results at a scale  $\mu_0 = 1$  GeV were obtained. One specific feature of this model is that  $G_{F,\text{Model}}^q(x, x, \mu_0) = 0$  due to the absence of final state interactions. This is in obvious contradiction to parametrizations from data for  $G_F^q(x, x)$  [14], and the model does not properly describe the physics of  $G_F^q(x, x')$  in a small interval around  $x' \sim x$ . Nevertheless it may realistically probe the physics outside of this interval, i.e., where  $x'$  is further away from  $x$ . Under the approximation that the quark-photon matrix element  $G_F^{\gamma,q}$  is proportional to the quark-gluon matrix element  $G_F^q$  [7] one also has  $G_{F,\text{Model}}^{\gamma,q}(x, x, \mu_0) = 0$ . Hence, for massless quarks the asymmetry  $A_{UT}$  in (2) is completely determined by  $G_{F,\text{Model}}^{u,d}(x, x', \mu_0)$  and  $\tilde{G}_{F,\text{Model}}^{u,d}(x, x', \mu_0)$  at a fixed scale  $Q = 1$  GeV. The model prediction for  $A_{UT}$  is shown in Fig. 1. In this plot fixed target kinematics have been used for an electron beam energy  $E = 12$  GeV (JLab12 kinematics). A missing mass  $W = (P + q)^2 > 4 \text{ GeV}^2 = W_{\text{min}}$  was assumed to ensure that the asymmetry is probed in the DIS region. This defines a maximal Bjorken- $x$   $x_{B,\text{max}} = Q^2/(Q^2 + W_{\text{min}} - M^2) \sim 0.25$  for  $Q = 1$  GeV. For a fixed scale the energy transfer from the electron to the nucleon  $y$  varies with  $x_B$ , that is,  $y = Q^2/(2ME x_B)$ . Typical experimental values  $y \sim 0.4 - 0.6$  are probed at  $x_B \sim 0.1$  at  $Q = 1$  GeV.

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<sup>(1)</sup> Definitions in terms of hadronic matrix elements for both functions can be found in Ref. [10].

<sup>(2)</sup> Notice a slight redefinition  $G_F^\gamma(x, x) \equiv \frac{1}{2e^2} F_{FT}(x, x)$  of the object  $F_{FT}$  introduced in [7].

<sup>(3)</sup> Note that  $G_F^q(x, x') = G_F^q(x', x)$  and  $\tilde{G}_F^q(x, x') = -\tilde{G}_F^q(x', x)$ . Hence,  $\tilde{G}_F^q(x, x) = 0$ .

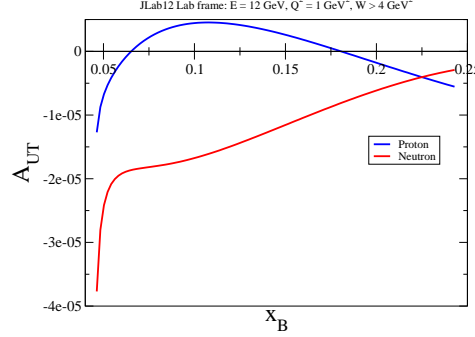


Fig. 1. – Prediction for the asymmetry  $A_{UT}$  at JLab12 obtained from a model [13].

#### 4. – Conclusions

The plot in Fig. 1 shows that one can expect rather small asymmetries of about  $10^{-5}$  from the model of Ref. [13]. Although the JLab data [3] for the SSA  $A_{UT}$  on a neutron is still preliminary it gives hints that the asymmetry is much larger in reality for a neutron. This discrepancy may point to missing physics in the integration region  $x \sim x'$  in Eq. (1) which is left out in the model of Ref. [13]. One may consider larger values of  $Q > 1$  GeV. At larger scales a non-zero "Soft Gluon Pole"  $G_F^q(x, x, \mu > 1 \text{ GeV}) \neq 0$  can be obtained from evolution of the model results of Ref. [13]. However, one would not expect the asymmetry to be dramatically larger at higher scales due to the factor  $M/Q$  in Eq. (1).

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